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REVIEW ON PRODUCTION AND UTILIZATION OF FLY ASH: AN INDIAN PERSPECTIVE

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ABSTRACT

A rapidly developing economy creates surge in energy demand and forced to find various alternative energy sources. Though many non-conventional energy sources have come up in the energy landscape, the t dependency on coal-based energy has not been reduced. Continuous coal burning generates huge quantity of Fly Ash and creates problems of storage, transportation, and management for power plants. If the fly ash generated is not handled properly, it poses a serious threat to ecology and the environment. The present study begins with focusing on the importance of coal in the Indian energy sector and discuss the status of fly ash generation and utilization throughout the years. It also focuses on how enforced laws and regulations help for management of fly ash. It emphasizes fly ash classification and physical-chemical characteristics, then, elaborates on the different sectors that have adopted fly ash as resource material and proven its worth over a time. This review attempts to highlight the current status of fly ash management in India which contributes to environmental and natural resources conservation.

KEYWORDS: Fly Ash, Generation, Utilization, Resource Material

INTRODUCTION

India is progressing fast and has emerged in the top 5 economies in terms of GDP (World Bank, 2023). It is driven by a robust power generation scenario and at present, it is world's 3rd largest consumer of energy in absolute terms. To cope up with the energy demands, the nation depends heavily on the current fossil fuel reserves. Though India's fossil fuel reserves are relatively lower than the rest of the world, it has the world's 9.4% proven reserves of coal and this is the reason behinds coals dominance in the energy consumption matrix of primary fuels. (Fig. 1).

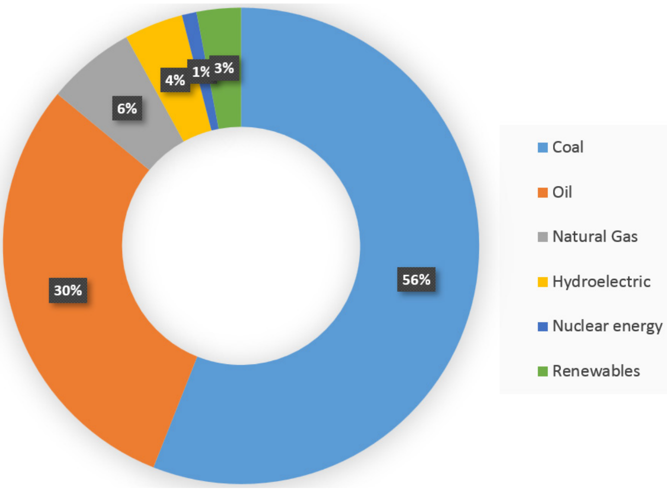

Fig.1: Primary Energy Consumption matrix of commercial fuel India, 2017 (Source: CEA 2021-22)

Energy produced from coal/ lignite-based power plants has been playing a major role in the overall power capacity of India since the beginning. Most primarily bituminous and sub-bituminous type of coal which contain 30-60% of ash. Using such kind of coal resulting into generation of huge quantity of fly ash. The fly ash is considered as source of various kind of pollution and requires large area for storage. Ash ponds occupy 65,000 acres of land in India, and by 2020, it is anticipated that the country will have produced 225 million tons of ash. Unscientific FA disposal pollutes local ecosystems with heavy metals through erosion and leachate formation. In addition to taking up big spaces, fly ash can go airborne if not properly managed due to its weightlessness. Because of the mobilization of its toxic elements, dumping FA contaminates soils, vegetation, and surface and groundwater. Two major problems arise due to fly ash i.e. Land occupancy and source of environmental pollution. (Kumar V et al 2000, Bhattacharjee et al. 2002, Mathur AK et al. 2008) To achieve 100% utilization of fly ash, the Ministry of Environment and Forests has released a number of notifications aiming at reducing the environmental impact of fly ash and the amount of land needed for its disposal. Under the Ministry of Science and Technology (GOI), several technologies have been adopted and modified since 1994 to enable the safe and effective utilization of fly ash, increasing its utilization from 6.64 million tons in 1996–1997 to 270.82 million tons in 2021–22. Fly ash has been used as an alternative to another industrial resource, process, or application for a number of reasons, such as preventing environmental pollution, reducing disposal costs and dumping area, replacing other expensive resources, and generating financial benefits. The exploitation of coal fly ash has several applications in the construction sector, including

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structural fill and pavement, soil reclamation, soil amelioration, zeolite synthesis, metal recovery, anaerobic digestion and composting, and low-cost adsorbent for a range of gaseous and aqueous applications. In this review, utilization status of fly ash is discussed aiming increasing utilization and reducing its impacts on environment.

Fly Ash Characteristics

1. Classification

Fly ash produced by coal combustion is defined using one of the most popular methods, American Society of Testing Materials (ASTM) C618 (ASTM, 2018). Fly ash can be divided into two groups using this method: Class "F" and Class "C." Based on the type of coal utilized for burning, this classification Class F fly ash is produced when anthracite or bituminous coal is burned, whereas class C fly ash is produced when lignite or sub-bituminous coal is burned. Since Class C fly ash contains more than 20% lime, it doesn't need an activator to help cementitious compounds form. Nevertheless, Class F fly ash needs an activator to create a cementitious compound because it has less than 10% lime concentration.

2. Physical Properties

Fly ash is the lightweight combustion residue generated after burning coal in coal-based power plants. Physically, these are very fine nonspherical particle sizes ranging from 0.5 to 100µm, having medium texture, high surface area, and low to medium bulk density. Specific gravity of fly ash can vary between 1.6-3.1 due to a combination of several factors such as chemical composition, shapes of particles and gradation.

3. Chemical Properties

Chemically, these ash particles consist of nearly 50% silica together with oxides forms of various elements. Major (95-99%) contributors of the compositions are silicon dioxide (SIO2) (both amorphous and crystalline form) Aluminum Oxide (Al2O3), Iron Oxide (Fe2O3) and Calcium Oxide (CaO), while minor (0.5-3.5%) contributors are Magnesium (Mg), Sodium (Na), Potassium (K), (Titanium (Ti), Sulfur (S) and Carbon (C). However, the physical and chemical composition of coal ash primarily depends upon the parent coal type and operating condition of the furnace used during combustion. The different types of coal and its composition are shown in Table no 1.

Component (mass%)	**Bituminous**	**Anthracite**	**Lignite**	**Sub-Bituminous**
Silicon Oxide as SiO_2	20-60	43.5-47.3	15-5	40-60
Aluminum Oxide as Al_2O_3	5-35	25.1-29.2	10-25	20-30
Iron Oxide as Fe_2O_3	10-40	3.8-4.7	4-15	4-10
Calcium Oxide as CaO	1-12	0.5-0.9	15-40	5-30
Magnesium Oxide as MgO	0-5	0.7-0.9	3-10	1-6
Sodium Oxide as Na2O	0-4	0.2-0.3	0-6	0-2
Potassium Oxide as K_2O	0-3	3.3-3.9	0-4	0-4
Sulphur trioxide as SO_3	0-4	-	0-10	0-2
Titanium Oxide as TiO_2	0.5	1.5-1.6	0.23-1.68	1.1-1.2
Phosphorus Oxide as $P2O_5$	0.02	0.2	-	0.3-0.5
Magnesium Oxide as MnO	0.02	0.1	0.04-0.21	0.1
Sulphur as S	0.08-0.67	0.1	-	0.7
LOI	0-15	8.2	0-5	1.8-2.7

Laws and Legislation for Utilization and Disposal

Traditionally coal ash (fly ash and bottom ash) generated after the burning of coal for electricity generation is being considered as waste and stored in large ash ponds in the vicinity of the power plants. The steady growth in electricity demands forced the power plants burning of more coal resulting the large extent of coal ash generation. Storage of such ash in traditional ash pond became the concern, as it required a huge land area, separate handling unit, cost of transportation, and the cost of bund raising to accommodate more ash. All the expenses have to be borne power plants just to manage the waste. In addition to that, there is a risk of ash dyke breach and spillage, which can cause harm to environment and society. To resolve the problem of land requirement and pollution caused by coal, fly ash utilization management and to boost the fly ash utilization mission throughout the nation, Ministry of Environment and Forest (MoEF) issued a regulation on 14th September 1999 specifying normative references for fly ash utilization. In response, ash has now been recognized as useful commodity and increased the demand for reuse and utilization (MoEF, 1999). To improve the utilization and effectiveness of the regulation has undergone time to time amendments on 27th August 2003, 3rd November 2009, 25th January 2016, and latest on 31st December 2021.

According to the first notification issued dated 14th Sept. 1999 both new and old (existing) coal-based thermal power plants should utilize 100% of produced fly ash within the stipulated time frame. Old power plants can achieve 100% utilization within 15 years from the date of issuance of regulation however, newly started power plants can achieve 100% status within 9 years after commencing the power generation. Notification published on 3rd November 2009 has mandated and reduced the time frame of 100% fly ash utilization i.e. existing (old) power plants within five years and for those commissioned after notification within four years. Goal of 100% utilization was observed to be deviated hence, MOEF&CC on 25th January 2016 amended the regulations to emphasize the efforts of effective utilization of fly ash. The amendment stipulates mandatory uploading of

current month's fly ash utilization and availability at the site inclusive of pond ash stock on Thermal Power Stations (TPSs) website. It also increases the jurisdiction of the area from 100km to 300km; up to 100km cost of transportation is to be entirely borne by TPS and when distance is more than 100km cost of transportation is to be shared between TPS and the actual user. The amendments also make mandatory use of fly ash products in programs and schemes started by the Government of India (GOI) like Swatch Bharat Abhiyan, Mahatma Gandhi National Rural Employment Guarantee Act, 2005, Pradhan Mantri Gram Sadak Yojana, Pradhan Mantri Awas Yojna etc.

As per the latest notification of MoEF&CC dated 31st December 2021, each power plant is responsible for utilizing 100% of the fly ash generated during the year, and in no case utilization percentage falls below 80%. In such cases, a power plant is required to achieve average utilization of 100% in a three-year cycle (MoEF&CC, 2021). It also states that, if a power plant has having option to dispose of fly ash and if any agency makes a request for it, in such case power plant may charge for the cost of the transportation and fly ash as per mutual understandings and agreed terms. If a thermal power plant serves a notice on construction agencies, then the provision of free-of-cost fly ash and transportation is applicable.

The main objectives of MoEF&CC for Fly Ash Utilization Acts is as follows (MoEF&CC 2022):

- Protecting the Environment
- Conserving Top-Soil by restricting its extraction for the purpose of brick manufacturing.
- Conserve Precious Land -Prevent the dumping and disposal of fly ash on precious land.
- Efficient Resource management leading to a circular economy.
- Zero waste policy – Utilization of fly ash rather than disposal
- Reduce land requirement for ash disposal.

UTILIZATION STATUS IN INDIA

MoEF&CC amended the Hazardous and Other Wastes (management and transboundary movement) Rules 2016 to support the fly ash utilization mission. Fly ash was classified as a high-volume, low impact waste, subject to the Toxicity Characteristics and Leaching Procedure (TCLP) being used to verify the fly ash's inorganic content (HWMR, 2016). Additionally, it modified the fly ash utilization notification, which now states that no manufacturer or individual located 300 kilometers or less from a thermal power plant may produce clay bricks, tiles, or blocks without incorporating at least 25% fly ash into the soil. For any building project, every construction company operating within a 300-kilometer radius must utilize solely fly ash-based building materials, such as cement, concrete, fly ash bricks, tiles, blocks, etc. This holds true for all building initiatives and organizations affiliated with the federal, state, municipal, commercial, or public sectors. It also helped to increase use in the surrounding area. India's consumption of fly ash has increased significantly over the years, from 9.63% (6.64 Mt out of 68.88 Mt) in 1996–1997 to (214.91 Mt out of 232.56 Mt)92.41% in 2021–2022 (CEA 2022). The total amount of fly ash generated increased 3.93 times over the specified period, while fly ash use increased 39.14 times during the same period (1996–97 to 2021-22).

It is reported (Annual Report of Central Electricity Authority for 2021-22) that in 2021-22, 270.82 million tons of fly ash were generated in 200 Thermal Power Stations, and 95.95 % (259.86 Million tons) was utilized in various sectors.

Over the years, India has enhanced the fly ash utilization percentage. India's fly ash generation was 40MnT/yr in 1993-94 and 275 MnT/yr in 2016-17 while it is projected to increase to 600 MnT/yr by 2031-32. Fly Ash utilization status is shown graphically in the following figure (Fig no 2).

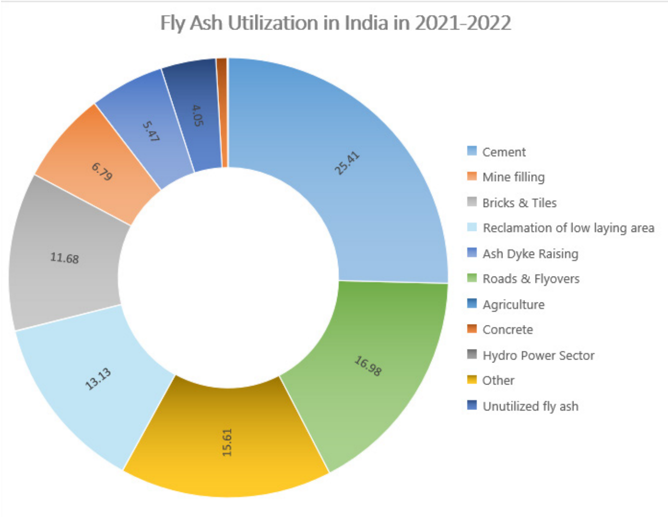

Fig. no. 2: Schematic diagram of fly ash utilization percentage in India. (Source: CEA 2022)

In 2021-22, out of 200 thermal power plants in India, only 92 power stations were able to achieve the utilization of 100%, whereas 18 of such power stations were not able to utilize their fly ash more than 50% (Table no. 2). It is observed that the percentage of fly utilization is depending upon the consumers' availability in the region where the Thermal Power Plant is situated. Power plants situated in states like Gujarat and Rajasthan are able to utilize 100% of fly ash whereas coal-producing regions like Mahanadi coal field, Talcher Coal fields, etc. are facing problems of utilization. The presence of cement industries in its vicinity has led to many power companies to achieve 110% fly ash utilization (Table no 2).

Sr. No.	Fly Ash Utilization %	No of Power Plants
1.	100% and >100%	92
2.	90% to <100%	19
3.	70% to <90%	34
4.	50% to <70%	28
5.	<50%	18
6.	No significant ash generation	9
	Total TPS	200

Table no. 2: Range of percentage of fly ash utilization in the year 2021-22 (Source CEA 2021-22)

Major Fly Ash Utilizing Sectors

In the last few decades, Various studies and research (MLD Jayaranjan et al. 2014, R B Panda et al. 2018, M Basu et al. 2008. SA Haldive et al. 2013) conducted in the field of fly ash utilization and management have led the steady growth in the utilization of fly ash in various sectors. Some of the major fly ash utilization sectors are discussed below.

a. Cement and Concrete Industries

Fly ash is the most dominant primary contributor in cement industries as a raw material and due to its binding abilities and pozzolanic properties, ordinary cement clinkers are replaced by fly ash. When fly ash is mixed with cement, its binding abilities improve the performance of concrete and reduce the cracking potential. Besides the financial advantages, using fly ash in Portland cement results in a significant reduction in bleeding, shrinking, the heat of hydration, and an increase in workability, ultimate strength, and durability. Mixing of fly ash without sacrificing the durability of the cement can reduce the environmental impacts. We can save precious limestone and at the same time, fly ash can be utilized. As per the International Energy Agency (IEA report 2023), clinker-to-cement ratio reduction has the potential to reduce direct CO_2 emissions reduction by 37%. In cement producing industries, the direct CO_2 emission intensity increased by 1.8% per year from 2015 to 2020. On the other hand, considering the steps towards Net Zero emission achievement in 2050 and increasing use of fly ash, it is predicted that, CO_2 emission intensity will decline by 3% annually. (IEA Report 2023).

In India, cement industries have been major consumers of fly ash for the last few decades and the amount of fly ash used in the concrete and cement industry has seen rapid growth from 19% in 1996 to 65% in 2017 (CMA, 2021). Major cement industries are situated in the regions of coalfields or in nearby regions where coal-based power plants are situated. Power plants in states like Gujarat and Rajasthan have utilized 100% of generated fly ash, and the major consumer is the state's cement industry. The cement industry has consumed 25.41 % means 68.83, million tons of fly ash generated in the year 2021-2022 whereas concrete industries consumed 2.21 million tons of fly ash.

b. Mine Backfilling

Mining of commercial minerals creates voids in the mining area which leads to structural instability and increases the risk of subsidence. To reduce the effect of subsidence, traditionally mine pit was stowed or backfilled by using different sizes of stones, river sand, etc. Stones create the compaction issue, while the availability of river sand in huge quantities has become an issue due to its growing demand. Physical properties of fly ash led miners to think of it as a substitute of sand for mine backfilling or stowing. It consumes 18.39 million tons of fly ash which accounts for 6.79% of total utilized ash in 2021-22.

c. Bricks & Tiles Making

Conventional clay was extensively being used for tiles and brick manufacturing industry but, in last few years, scenario has completely changed due to introduction of fly ash utilization in bricks manufacturing. This utilization triggered due to the latest (3rd Nov 2019) notification of MoEF&CC, which states that at least 20% of dry ash of any quantity shall be made available free of cost to bricks and tiles manufacturing units on first cum first serve basis. Engineered Fly ash-based bricks and tiles are far better than the conventional clay form as it reduces the resource consumption and it is lighter in weight. In FA-Lime-Gympsum (FaL-G) mixture when lime and gypsum react with oxide of FA, it develops different types of phases. Then , these phases reacted with water and formed hydrates. Strength, compaction, durability of this FaL-G hydrates is much stronger than the clay material (D K Nayak et. al. 2022) In India, annually more than one billion of such blocks are manufactured and sold by 700 plants. The production of such bricks is well accepted by peoples and in demand because its offering two-to-four-fold strength parallel price of conventional bricks. It has consumed 31.62 million tons of fly ash in year 2021-22 and contributed 11,68% of portion in total fly ash utilization (CEA 2021-22).

d. Reclamation of low laying areas

Over the period, topsoil was utilized for filling and compaction material in construction and other industries, resulting creation of low-laying areas in the vicinity. Reclaiming the area with other materials like sand or stones creates the compaction issue. The best substitute is the fly ash and its demand is increasing with time. In India, 35.56 million tons of ash is used for low laying area back filling and land reclamation (CEA 2021-22).

e. Ash Dyke Raising

Most of the power plants in India store their generated fly ash in Ash ponds in the vicinity of the power plants. These ponds are built with specific capacity and over a period need to be expanded vertically to accommodate further produce fly ash. Studies (C.Zevenbergen et al. 2000, Pradhip et al. 2023) found that hardened pond ash's shear strength and stability make it more suitable for dyke raising by increasing the base size at first stage and reducing height at second stage. Total 14.82 million tons of fly ash used for dyke and embarkments raising in year 2021-22 (CEA 2021-22).

f. Roads & Flyovers

Fly ash's engineering properties like particle size distribution, shear strength, compaction, permeability, compressibility, and frost susceptibility are reasons behind the increasing demand in the construction industry. Unlike the soil used in construction of roads, embankments and flyovers, fly ash has uniform particles which improve the compaction and resulting in reduction of time in handling & compaction, and cost incurred in types of equipment. The recent Indian government focus on building road networks and compulsion of the use of fly ash has seen an increase in the fly ash use percentage. Fly has contributed 16.98 % of total fly ash utilized in the year 2021-22 (CEA 2021-22).

g. Agriculture

In general, when fly ash is mixed with soil, fly ash reduces the bulk density of soils and improves workability, porosity, and water holding capacity. In addition, applying fly ash to sandy soil may result in long-term changes to the soil's microporosity and its texture. It has been observed that porosity, water-holding capacity, conductivity, and cation exchange capacity improve

with a progressive increase in fly-ash content in typical field soil. Plant growth benefits from this increase in water-holding capacity, particularly in rain-fed agriculture (Chang et al 1977 , Sarkar & Rano 2007). Deshmukh et al 2000 and Garg et al 2005 have found that fly-ash application in soil increased the crop yield of alfalfa (Medicago sativa), wheat (*Tritiucm aestivum*), barley (*Hordeum vulgare*), Sabai grass (*Eulaiopsis binata*), mung (*Vigna unguiculata*), bermudagrass (*Cynodon dactylon*), and white clover (*Trifolium repens*) and improved the physical and chemical characteristics of the soil. In addition, fly ash is acting like chemical fertilizers and reduce the use of pesticides in the field. This leads farmers to use fly ash in agriculture sector and utilization of fly ash in this sector has seen growing demand. In the year 2021-2022, 0.15 Million tons of fly ash for the agriculture sector was used (CEA 2021-22)

CONCERNS

Many researchers (Jambhulkar et al. 2018, Saurabh et al. 2023) reported the groundwater pollution, metal-leaching and biomagnification behavior of fly ash and raised concerns about the impact on ecology and the environment due to improper disposal or utilization.

CONCLUSION

Considering India's current economic growth, it seems coal consumption and fly ash generation growth will be steady for at least the next three to four decades. As of now, India has utilized 95.95% of generated fly ash in various sectors. Policy implementation and surveillance systems are focusing on achieving 100 % utilization. Fly ash generation is associated with many problems like space availability, economic viability, cost incurred on storage handling & transportation, and environmental and health impacts. Exploration of new utilizing sectors, proper storage, handling, and systematic planning of utilization can lead to the aim of 100% utilization of fly ash.

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